

Distributions of Indoor and Outdoor Air Pollutants in Rio de Janeiro, Brazil: Implications to Indoor Air Quality in Bayside Offices

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An indoor air quality survey was conducted on selected floors in an office building in Rio de Janeiro, Brazil. The sampling sites comprised four offices located along the same vertical column of the building. Measurements were made on alternate days at the same time of day during working hours. Indoor and outdoor samples were collected for volatile organic compounds (VOC), formaldehyde, total suspended particles (TSP), nicotine, and ultraviolet respirable suspended particles (UV-RSP). Compared with formaldehyde, acetaldehyde was found in higher concentrations outdoors because of the use of ethanol or ethanol/gasoline blends as alternative fuels for automobiles in Brazil. The TVOC concentration ranged from 304.3 to 1679.9 $\mu\text{g}/\text{m}^3$ indoors and 22 to 643.2 $\mu\text{g}/\text{m}^3$ outdoors. The indoor level of total volatile organic compounds (TVOC) was especially high in the 13th floor office. A minor contribution from environmental tobacco smoke was found. TSP values exceed the Brazilian Legislation (80 $\mu\text{g}/\text{m}^3$) in both outdoor and indoor air in the office located near the street traffic. For all pollutants evaluated I/O ratios appeared to be higher in offices located on the top of the building. The characterization of indoor air pollutants allowed the suggestion of several remediation measures to improve air quality in the offices.

Introduction

Indoor air quality (IAQ) is an important component of work environment. Poor air quality produces discomfort, decreases employee concentration, and increases absenteeism. Conversely, improved indoor air quality can lead to improved productivity. Pollutant levels may vary over relatively brief periods of time, as both source strengths and exposures can change rapidly. For instance, trivial actions such as walking across carpets, opening a typewriter correction fluid container, or improperly using cleaning materials can airborne hazardous substances (1, 2). Similarly, operation of laser printers, photoduplication machines, vacuum cleaners, or even toilet flushings are known sources of indoor air pollution. Inadequate ventilation (in air-conditioned buildings) may also result in accumulation of pollutants. Knowledge of the pollutant concentrations both indoors and outdoors is

therefore critical for an evaluation of their potential health effects. Most of the research in IAQ that has been done in developed countries will not apply in developing nations such as Brazil, due to the differences in climate, housing, and socioeconomical conditions.

Rio de Janeiro is an Oceanside and bayside city located in southeastern Brazil where the rapid and unplanned expansion of the urbanized areas caused a very serious urban air pollution problem (3). With a population of 7.3 million, the second most populated city in Brazil, Rio has been presented with an overpopulation problem which created a lower standard of living. To make matters worse, despite the fact of being a coastal city, Rio de Janeiro is also surrounded by mountains which create unfavorable ventilation regimes (4). The effect on overall outdoor pollution in the city is yet to be established. Building related air quality illnesses have attracted a lot of publicity in Brazil in recent years. Individual living and working conditions in buildings subjected to energy conservation measures have become associated with various health symptoms due to the poor indoor environment. Although a significant part of the Brazilian population spends most of their time inside buildings, the indoor air quality issue has been relatively overlooked (5-7).

It is well-known that poor urban air quality may be hazardous and pose risks to people in indoor areas. The principal contribution to urban air pollution in Rio de Janeiro comes from motor vehicles because the majority of public transportation is made by buses using diesel fuel. One aspect which makes Brazilian urban air pollution different from other countries is the use of hydrated ethanol and ethanol-gasoline (gasohol) mixtures as fuel for light-duty vehicles since the mid 1970s (8). Cars run on 95% alcohol or anhydrous alcohol-gasoline mixtures, which are not evenly standardized. This creates not only inefficient combustion engines but also exhaust gases not compatible with catalysts which have become mandatory in new vehicles since 1992. Additionally, incomplete vehicle combustion or evaporative losses from fuel tanks should also be considered relevant sources of pollutants in urban air. To aggravate the situation, there is no adequate law enforcement to make vehicles operate properly, and black smoke emissions from buses and trucks around the city are common.

Considerable concern has been voiced over possible health effects from exposures to pollutants in indoor air, especially for volatile organic compounds (VOC) (9). VOC are widespread pollutants indoors due to their popular use in several ways. Thus, they play an important role in indoor atmospheric chemistry. Some of these VOC are considered potential risk factors for causing cancer in humans. This study is part of an indoor air quality program investigating the concentrations of VOC, total suspended particulate, and nicotine in Brazilian offices. The goal of this study was to investigate, on a vertical column, the influence of urban air pollution (street traffic) upon indoor air quality and to evaluate indoor sources.

Experimental Section

Building Characteristics. The climate in Rio de Janeiro is tropical with monthly mean temperatures varying between 21 °C (June/July) and 29 °C (January/February). Situated at a latitude of 22°54' S, and longitude of 43°10' W, the city experiences a climate with uniformly high yearly temperature, high humidity, and abundant rainfall averaging 2381 mm a^{-1} . Sampling was carried out during one week in December 1995. Sampling locations were selected after evaluating the

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building's ventilation and air-conditioning (AC) system. Each floor in the building is serviced by its own fan room. These units are constant volume systems. Fresh air intake for all floors is located on the main floor AC system in the back of the building. The AC system is turned off overnight and during weekends. Based on complaints about high temperature on the right side of the building, due primarily to solar radiation during mornings and afternoons, this facade was considered as "worst-case scenario" and selected to locate the sampling points.

Sampling Strategy and Analytical Measurements. A total of four sampling points were selected. Three sampling floors were selected according to distance from street traffic: 1st, 13th, and 25th floors, respectively. The ninth floor was also included for sampling because this floor was being renovated. Outside and inside air measurements were taken simultaneously. Several environmental measurements were performed, namely dry-wet bulb temperature, aldehydes, VOC, nicotine, and suspended particulate matter. Samplings were made for 6 h during daytime, with the office normally occupied.

The air monitoring system consisted of area stations outfitted with pulsation-free diaphragm air sampling pumps with rotameter flowmeters. Pollutants were concentrated by pulling air through a manifold containing adsorbent tubes and filters using dual-head air cadet pumps (Cole Parmer, Niles, IL). Formaldehyde and acetaldehyde samples were collected on C₁₈ Sep-Pak cartridges impregnated with an acid solution of 2,4-dinitrophenylhydrazine (10). Sample volumes amounted to 360 L collected over about 6 h. The aldehyde samples were analyzed by an isocratic HP model 1050 HPLC system fitted with a variable wavelength UV-detector adjusted to 365 nm. The sample volume was 20 μ L. Separation was performed on a C₁₈ column (Merck Lichrocart C₁₈ 125 \times 4.6 mm, 5 μ m). The flow of acetonitrile/water (55:45) mobile phase was adjusted to 1 mL/min. An internal standard, consisting of 5 ppm of cyclohexanone (as 2,4-dinitrophenylhydrazine) was added to samples prior to analysis. The analytical precision for individual compounds in replicate samples was typically 10% or better. Quantification of the integration results was based on a least-squares analysis of standard calibration curves.

Airborne nicotine was collected by drawing air, at a rate of 1 L/min, through a sorbent sampling tube containing XAD-4 resin (SKC Inc.). After sampling, the tube was capped and returned to the laboratory. The collected nicotine was extracted by ethyl acetate (modified with 0.01% v/v triethylamine) directly in the autosampler vial; an internal standard, consisting of 1 ppm of quinoline, was added to the samples prior to capping the vials (11). The determination was done using a HP 5890 series II gas chromatograph, a HP 7673 autosampler, and 1.0 μ L splitless injections in conjunction with a HP3396 recording integrator. Conditions were the following: HP-5 capillary column (25 m, i.d. 0.2 mm, df = 2 μ m); temperatures of the injector and detector were set at 250 and 290 $^{\circ}$ C, respectively; the GC heating profile was 150 $^{\circ}$ C, programmed at 8 $^{\circ}$ C \cdot min $^{-1}$ to 180 $^{\circ}$ C; NPD bead energy was 620–650. The analytical precision for individual compounds in replicate samples was typically 10% or better. Quantification of the integration results was based on a least-squares analysis of standard calibration curves.

Ultraviolet respirable suspended particles (UV-RSP) were collected by drawing air at 1 L/min through a 37-mm fluoropore membrane filter (Millipore, Bedford, MA) after passing through a single-stage impactor that removed particles larger than 5 microns (SKC Inc.). Each filter was extracted with methanol, and the resulting solution was analyzed for its absorbance at 325 nm (12). 1,1,2,2-Tetrahydroxybenzophenone was used as a surrogate standard for calibration.

TABLE 1. Pollutants and Physical Parameters Evaluated in This Study^a

pollutants (μ g/m ³)	indoor		outdoor	
	mean	range	mean	range
TSP	70.5	42.7–91.8	81.2	40–151
nicotine	0.7	0.4–1.7	0	ND–0.1
UV-RSP	8.0	5.2–13.5	4.2	ND–7.1
formaldehyde	40.0	12.2–99.7	14.5	7.1–21.0
acetaldehyde	20.5	2.4–35.9	17.0	8.8–27.8
TVOC	803.2	304.2–1,680	216.5	22.2–643.2
Physical Parameters				
T ($^{\circ}$ C)	24.4	20–29	28.7	21.5–32.5
RH (%)	63.2	60–67	74	72–76

^a Abbreviations: TSP, total suspended particles; UV-RSP, ultraviolet respirable particulate matter; TVOC, total volatile organic compounds; RH (%) percent relative humidity; ND: not detected.

Total suspended particles was measured by gravimetric analysis. Air from the environment was drawn at 12 L \cdot min $^{-1}$ onto 37-mm diameter polycarbonate membrane filters (0.4 μ m) mounted in plastic cassettes. Filters were preconditioned to constant humidity in a desiccator containing 80% (p/p) glycerol/water before and after sampling. Weighing was on a Cahn G-2 microbalance. Both laboratory blanks (unexposed monitors that remained in the laboratory) and field blanks (unexposed monitors taken to the field with sample monitors during sampling) were analyzed.

VOC were collected on cartridges containing two sections of activated charcoal, one for sampling (100 mg) and the other for checking a possible breakthrough (50 mg). The collected VOC were extracted by dichloromethane directly in the autosampler vial, and an internal standard, consisting of 9.9 ng of cyclohexane-*d*₁₂, was added to samples prior to capping the vials (13). The VOC (individual components and TVOC) were quantified from the responses of the FID detector and identified by GC-MS. Solvent extraction methods do not allow quantification of highly volatile VOC, so the term TVOC used in this paper describes VOC identified between hexane and dodecane. In gas chromatographic analyses, the temperatures of the injector and detector were set to 250 and 290 $^{\circ}$ C, respectively. The column was a HP-5 silica capillary column (50 m \times 0.35 mm i.d.; 0.5 μ m film thickness). The GC heating profile was 5 min at 30 $^{\circ}$ C, programmed at 10 $^{\circ}$ C \cdot min $^{-1}$ to 200 $^{\circ}$ C, hold for 5 min. The flow of carrier gas, hydrogen, was 3.6 mL \cdot min $^{-1}$. Before each set of analyses, a Grob test (14) was done to check the performance of the chromatographic column. Compounds were identified by GC/MS. Analytical conditions were similar to those used in gas chromatographic analyses. The MS system was operated in the electron impact mode at 70 eV. The scanning was from 33 to 300 amu. A HP 5970 MS ChemStation with a Wiley 257.L spectral library was used for compound identification. The percent-relative humidities and temperatures were measured using a sling psychrometer.

Results and Discussion

Table 1 shows the concentrations found for all the pollutants studied in this survey. A discussion of the results is presented below.

Aldehydes. The formaldehyde and acetaldehyde results are summarized in Table 2. Formaldehyde concentrations ranged between 12.2 and 121.7 μ g/m³ for indoor air and 7.1–21 μ g/m³ for outdoor air, whereas the acetaldehyde levels were between 2.4 and 48.5 μ g/m³, for indoor, and 8.8–27.8 μ g/m³, for outdoor air. The aldehyde concentrations are higher indoors, except at the ninth floor office, for acetaldehyde. The use of ethanol for cleaning surfaces (notably glass windows) in Brazil is very common, and this appears

TABLE 2. Variation of Aldehyde Levels ($\mu\text{g}/\text{m}^3$) during the Week*

floor	date	formaldehyde			acetaldehyde		
		indoor	outdoor	I/O	indoor	outdoor	I/O
1st	12/18/95 (Mon)	47.4	20.1	2.4	19.5	22.5	0.9
	12/20/95 (Wed)	44.9	19.5	2.3	24.0	18.8	1.3
	12/22/95 (Fri)	33.6	19.7	1.7	27.6	27.8	1.0
	mean	42.0	19.7	2.1	23.7	23.0	1.0
9th	12/19/95 (Tue)	87.9	18.6	4.7	5.9	19.2	0.3
	12/21/95 (Thur)	99.7	21.0	4.7	2.3	17.9	0.1
	mean	93.8	19.8	4.7	4.1	18.6	0.2
	12/18/95 (Mon)	23.2	11.3	2.0	35.9	18.0	2.0
13th	12/20/95 (Wed)	23.1	14.1	1.6	28.4	15.9	1.8
	12/22/95 (Fri)	12.2	10.9	1.1	25.9	16.8	1.5
	mean	19.5	12.1	1.6	30.1	16.9	1.8
	12/18/95 (Mon)	29.8	8.8	3.4	21.4	9.9	2.2
25th	12/20/95 (Wed)	21.3	7.9	2.7	22.7	11.5	2.0
	12/22/95 (Fri)	16.5	7.1	2.3	11.6	8.7	1.3
	mean	22.6	7.9	2.8	18.6	10.0	1.8

* Abbreviations: I/O, indoor/outdoor ratio; Mon, Monday; Tue, Tuesday; Wed, Wednesday; Thur, Thursday; Fri, Friday.

to be the major source of acetaldehyde indoors because acetaldehyde is a usual contaminant in commercial ethanol. The high level of acetaldehyde at the 13th floor can be justified because that particular office is cleaned more often than the other offices. By the same token, the ninth floor office, which was being renovated at the time of sampling (no cleaning activities), showed the lowest level of acetaldehyde. Therefore, the erratic values for acetaldehyde indoors could be attributed to variable emissions due to random cleaning activities using ethanol. This seems to confirm that ethanol as a cleaning agent is the major source of acetaldehyde in the indoor environments evaluated.

Formaldehyde levels are a good indicator of the effect of the air conditioning regime in indoor pollutant concentrations (Table 2). All but the ninth floor showed a decreasing trend in concentration, from Monday through Friday, following the weekend air conditioning interruption. The ninth floor had its air conditioning system turned off during the refurbishing period.

Some test chamber measurements of Brazilian vehicular emissions with pure ethanol fuel indicate that extremely high emission ratios of acetaldehyde to formaldehyde are obtained (15). These data indicate that high outdoor levels of acetaldehyde should be expected for urban air in Brazil, mainly because Brazilian automobiles are not generally equipped with catalytic converters. Another study confirms the predominance of acetaldehyde in Brazilian urban atmospheres (16) due to the use of ethanol as automobile fuel. Our results are reasonably consistent with these findings about the prevalence of acetaldehyde in the Brazilian urban atmosphere. On the other hand, consistently higher indoor/outdoor levels of formaldehyde point to the importance of indoor over outdoor sources. It is clear from Table 5 that formaldehyde is not related to VOC classes, indicating a specific source for this compound. Acetaldehyde showed a better correlation with TVOC_{TER} (Table 5). The major source of terpenes indoors is cleaning products. This result confirms that the presence of both acetaldehyde and terpenes indoors is related to cleaning activities.

Distribution of VOC by Chemical Class. The mean VOC concentrations measured in the offices are given in Table 3 and illustrated in Figure 1. VOC commonly detected can be divided into five categories. The largest classes are the aliphatic and aromatic hydrocarbons. The compounds in these two classes are derived from petroleum distillate-type solvents. Chlorinated hydrocarbons made up the third

TABLE 3. Average of Indoor and Outdoor VOCs ($\mu\text{g}/\text{m}^3$) in the Offices*

class	compound	floor											
		1st			9th			13th			25th		
		I	O	I/O	I	O	I/O	I	O	I/O	I	O	I/O
AL	hexane	91.1	60.7	1.5	119.6	43.5	2.7	125.5	38.4	3.3	60.7	5.2	11.7
AL	methylcyclopentane	58.2	18.8	3.1	42.8	7.1	6.0	8.4	13.2	0.6	17.3	ND	NA
AL	heptane	37.5	20.7	1.8	39.2	7.5	5.2	54.1	18.9	2.9	12.9	2.8	4.6
AL	methylcyclohexane	25	11.9	2.1	31.9	4.5	7.1	36.1	11.9	3.0	8.4	ND	NA
AL	octane	5.4	27.6	0.2	16.9	5.4	3.1	32.1	9.4	3.4	8.3	1.6	5.2
AL	nonane	11.0	5.3	2.1	10.3	6.3	1.6	27.7	7.4	3.7	9.2	2.7	3.4
AL	decane	14.8	13.4	1.1	16.3	8	2.0	53.3	12.6	4.2	13.0	ND	NA
AL	undecane	12.9	7.0	1.8	13.4	7.4	1.8	40.7	10.4	3.9	14.7	2	7.3
AL	others	60.9	26.7	2.3	66.5	15.5	4.3	143.0	11.0	13	46.2	ND	NA
VOC _{AL}	Σ	316.8	192.1	1.6	356.9	105.2	3.4	520.9	133.2	3.9	190.7	14.3	13.3
AR	benzene	18.4	11.6	1.6	31.1	9.9	3.1	34.5	12.2	2.8	15.9	3.3	4.8
AR	toluene	116.1	52.6	2.2	293.7	31.9	9.2	320.5	60.2	5.3	102.0	8.9	11.5
AR	ethylbenzene	13.1	7.4	1.8	13.6	5.8	2.3	21.2	7.3	3.0	9.3	3.1	3.0
AR	xylenes	36.6	18.0	2.0	38.7	15.8	2.4	60.6	19.9	3.0	24.4	3.7	6.6
AR	ethyltoluene	19.7	10.8	1.8	14.4	12.4	1.2	15.3	ND	NA	21.1	ND	NA
AR	others	48.6	21.2	2.3	57.3	13.7	4.2	93.5	11.3	8.3	39.6	ND	NA
VOC _{AR}	Σ	252.5	121.6	2.1	448.8	89.5	5.0	545.6	170.9	4.9	212.3	19.0	11.2
CL	chloroform	3.9	1.6	2.4	4.8	ND	NA	6.2	1.5	4.1	2.0	ND	NA
CL	methylchloroform	4.4	1.7	2.6	2.6	ND	NA	4.7	ND	NA	5.2	ND	NA
VOC _{CL}	Σ	8.3	3.3	2.5	7.4	ND	NA	10.9	1.5	7.3	7.2	ND	NA
TER	pinene	13.1	ND	NA	12.5	ND	NA	14.7	ND	NA	6.0	ND	NA
TER	limonene	52.0	ND	NA	2.15	ND	NA	16.7	ND	NA	5.6	ND	NA
TER	others	14.5	3.6	4.0	13.2	ND	NA	25.3	ND	NA	5.2	ND	NA
VOC _{TER}	Σ	79.6	3.6	22.1	27.9	ND	NA	56.7	ND	NA	16.9	ND	NA
OX	ethyl acetate	31.7	25.5	1.2	27.5	21.2	1.3	34.1	25.7	1.3	23.0	5.0	4.6
OX	1-butanol	20.3	ND	NA	20.7	ND	NA	27.6	ND	NA	ND	ND	NA
VOC _{OX}	Σ	52.0	25.5	2.0	48.2	21.2	2.3	61.7	25.7	2.4	23.0	5.0	4.6
TVOC	Σ	709.2	346.1	2.0	889.2	215.9	4.1	1196	271.3	4.4	450.1	38.3	11.8

* Abbreviations: I, indoor air; O, outdoor air; AL, aliphatic hydrocarbons; AR, aromatic hydrocarbons; CL, chlorinated; OX, oxygenated; TER, terpene; I/O, indoor/outdoor ratio; ND, not detected; NA, not applied.

TABLE 4. Averages ($\mu\text{g}/\text{m}^3$) of Measured TSP, Nicotine, and UV-RSP in the Offices

floor	TSP			nicotine			UV-RSP		
	indoor	outdoor	I/O	indoor	outdoor	I/O	indoor	outdoor	I/O
1st	91.4	141.4	0.7	1.5	ND	NA	10.4	5.8	1.8
9th	28.7 ^b	32.8 ^b	0.9	ND	NA	NA	7.7	5.5	1.4
13th	53.5	58.8	0.9	0.7	ND	NA	6.6	5.0	1.3
25th	66.6	43.5	1.5	0.5	ND	NA	8.1	1.8	4.5

* Abbreviations: TSP, total suspended particles; UV-RSP, ultraviolet respirable suspended particles; I/O, indoor/outdoor ratio; ND, not detected; NA, not applicable. ^b Inhaled suspended particles.

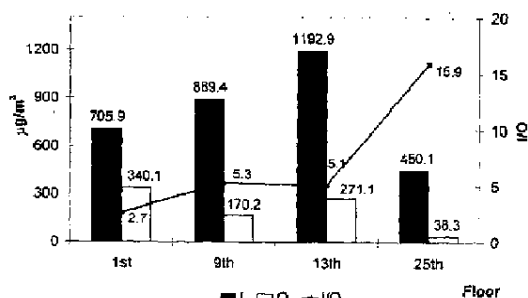


FIGURE 1. Indoor and outdoor TVOC concentrations in the offices.

class. The main indoor source of this class is consumer products, whereas outdoor sources are both anthropogenic and natural marine (17, 18). The fourth class was the terpenes which were detected only indoors, indicating that the presence of terpenes indoors is probably related to their presence in cleaning products. Oxygenated compounds (esters and alcohols) comprised the remaining class.

TVOC values are very useful in the assessment of the quality of indoor air. In 1994 Molhave and Seifert proposed the use of a target guideline of $300 \mu\text{g}/\text{m}^3$ of TVOC as an indicator of health effects caused by a multicomponent air exposure to VOC at low concentrations (19). In Australia, the National Health and Medical Research Council has recommended $500 \mu\text{g}/\text{m}^3$ as the level of concern for TVOC with no single compound contributing more than 50% of the total (20).

Our measurements have demonstrated that values of TVOC concentrations in the offices are high enough, in light of Molhave's studies, to cause discomfort in occupants (especially sensitive individuals). Indoor TVOC concentrations ranged up to $1680 \mu\text{g}/\text{m}^3$ with an average of $803.2 \mu\text{g}/\text{m}^3$ (Table 1); comparison of these concentrations showed significantly higher concentrations in the 13th floor office. The TVOC outdoor air concentration decreases with distance from street traffic indicating a strong contribution from outdoor air in lower floors. These results are consistent with a Manila study (21), showing that sites near high street traffic showed the highest levels of VOCs, whereas sites located 30 m or more from the street traffic showed the lowest levels.

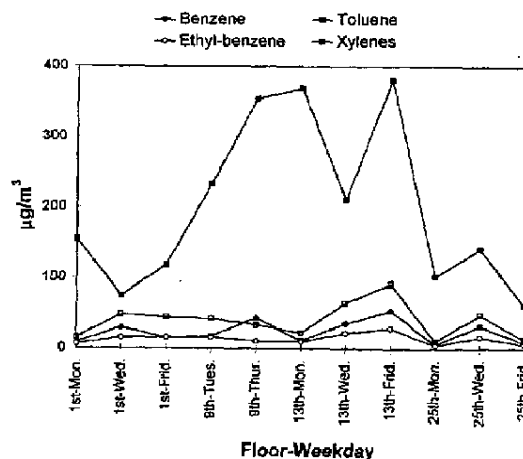


FIGURE 2. Variation of indoor BTEX levels in the offices during the week.

The distribution of VOC classes in the outdoor and indoor air varies due to their different emissions sources. The absolute amounts of the compounds also varied widely between the offices. Indoor/outdoor ratios for VOC classes and TVOC were generally above one, as shown in Table 3, indicating that the VOC found in the indoor air originate mainly from indoor sources. In terms of the hydrocarbon fraction, a higher level of aliphatic hydrocarbons was noted in outdoor air, whereas indoors, the total concentration of aliphatic and aromatic fractions were similar with a slight prevalence of aromatic hydrocarbons. The best explanation for these results will be that the main outdoor source of VOC in this study is street traffic, as there are no industrial facilities nearby. Fuel composition is richer in aliphatic compounds than in aromatics. As a consequence, when volatilization occurs, a greater amount of aliphatic compounds is released into the urban atmosphere. In indoor air, on the other hand, there is a greater diversification of sources, contributing for a larger variety of volatile compounds.

Several kinds of alkanes and cycloalkanes were detected. *n*-Alkanes, methylcyclopentane, methyl-ethyl, and *n*-propyl cyclohexanes were identified, while the exact structures of several isomers of other alkanes and cycloalkanes were not characterized. The mass concentration of hexane, for example, shows $125.5 \mu\text{g}/\text{m}^3$ as the indoor maximum value. Benzene, toluene, ethylbenzene, and the three xylene isomers (*para*-, *ortho*-, and *meta*-) (BTEX) are often used as target compounds in environmental studies due to their potential health risks. Actually, they were the main compounds identified among the aromatics. They are present in higher concentrations indoors (Figure 2), relative to outdoor air (Figure 3), especially toluene, which showed levels higher than $300 \mu\text{g}/\text{m}^3$ (Molhave's suggested limit for TVOC in the indoor environment). Indoor concentrations of 15.9–34.5 $\mu\text{g}/\text{m}^3$ for benzene, 9.3–21.2 for ethylbenzene, and 24.4–60.6 for xylenes were measured. The xylene isomers,

TABLE 5. Correlation Matrix: Indoor Environmental Parameters^a

	VOC _{AL}	VOC _{AR}	VOC _{CL}	VOC _{TER}	VOC _{OX}	form.	acetal.	TSP	UV-RSP	nicotine
VOC _{AL}	1.0	0.823	0.804	0.258	0.895	0.087	0.190	0.256	0.015	0.119
VOC _{AR}	0.823	1.0	0.500	0.078	0.716	0.070	0.143	0.604	0.300	0.344
VOC _{CL}	0.804	0.500	1.0	0.121	0.618	0.255	0.166	0.033	0.163	0.151
VOC _{TER}	0.258	0.078	0.121	1.0	0.472	0.089	0.459	0.573	0.305	0.817
VOC _{OX}	0.895	0.716	0.618	0.472	1.0	0.036	0.182	0.169	0.214	0.140

^a Abbreviations: TSP, total suspended particles; VOC_{AL}, total aliphatic VOC; VOC_{AR}, total aromatic VOC; VOC_{CL}, total chlorinated VOC; VOC_{TER}, total terpene VOC; VOC_{OX}, total oxygenated VOC; form., formaldehyde; acetal., acetaldehyde; UV-RSP, ultraviolet respirable suspended particles.

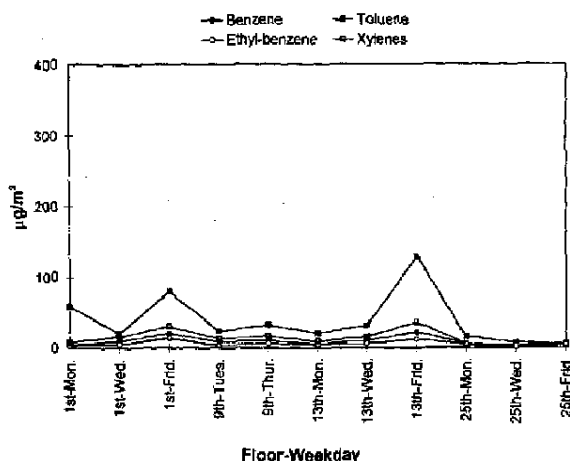


FIGURE 3. Variation of outdoor BTEX levels in the floors during the week.

ethylbenzene, and toluene have been reported as chemicals present in paint (22).

All indoor samples included several types of terpenes. The main terpenes were α -pinene and limonene. α -Pinene (pine) and limonene (lemon scent) are found as odorants and room "deodorizers". Recently, Pasanen et al. (23) reported terpene emissions from microbiological activities, indicating another source of these compounds indoors.

The most striking feature in these results is the contrast between indoor and outdoor concentrations in the upper floor. There are many compounds detected only indoors (e.g., ethyltoluene, methylcyclohexane). In cases where the same compound is detected both indoors and outdoors, the indoor concentration is frequently much higher (e.g., toluene).

This study identified VOC classes which have adverse effects, such as halogenated hydrocarbons (24), aliphatic, and aromatic solvents (25, 26) that may affect the immune function. However, there is no Brazilian legislation or even toxicity data regarding multiexposure to low levels of those contaminants for nonindustrial environments. An overview of the first southeastern Brazil indoor air quality study (6) showed lower levels of TVOC, in comparison with the present results, ranging between 6.9 and 568.0 $\mu\text{g}/\text{m}^3$, for indoor air, and between 6.4 and 138.1 $\mu\text{g}/\text{m}^3$, for outdoor air. Comparisons and conclusions are however premature, in view of the limited data available for Brazilian indoor environments, not necessarily representative of the range of building types, geographical areas, and population groups that occur in Brazil.

Effect of Smoking: Nicotine and UV-RSP. It is clearly important to establish the role of smoking in the air quality of the indoor environment. Currently in Brazil, tobacco smoking is commonly prohibited in commercial and public buildings, but people still smoke in those places. Indoor nicotine values found were 0.4–1.7 (Table 4), except on the ninth floor office where nicotine was not detected (low occupancy due to refurbishing work). To investigate the effects of environmental tobacco smoke (ETS) on the indoor air quality, correlation coefficients were calculated for the TVOC and ETS parameters monitored. Table 5 shows there is no relationship between nicotine and UV-RSP and specific VOC classes, except between nicotine and VOC_{TER}. The reason behind this correlation is uncertain but may be related to the use of deodorants to "hide" tobacco smoke smell, as other VOC are expected to be more abundant in tobacco smoke than terpenes.

Total Suspended Particles. Table 4 shows the averages of TSP at the evaluated offices. As a consequence of the

heavy street traffic, outdoor TSP values are very high, especially on offices located at ground level. For example, the outdoor air sampled located at the first floor had a maximum TSP value of 151 $\mu\text{g}/\text{m}^3$, almost 50% above the Brazilian federal standard (80 $\mu\text{g}/\text{m}^3$) for the annual average TSP concentration (27). However, the maximum indoor TSP value at that site was 91.7 $\mu\text{g}/\text{m}^3$, about 14% above that standard.

The major contribution to urban air pollution at site location come from the liquid fossil fuels predominantly used in motor vehicle transportation. The motor vehicle emission rates are significantly high in Brazil due absence of standards and government control. In 1997 the municipal government has taken the first step to improve urban air quality. From this year on, all registered vehicles have to be checked for smog test in the city of Rio de Janeiro.

It is interesting to note that indoor TSP values showed a better correlation with VOC_{TER}, when compared with the other pollutants analyzed (Table 5). This suggested a build up of TSP due to cleaning activities.

Possible Remediation. Our investigations suggest that appreciable improvement may be obtained by better control of the climatological parameters and reduction of airborne pollutants. There are a number of specific actions that can be taken to improve the indoor air quality at the office building studied. These include the following:

- (a) modification of the outdoor air intake. It should be on the top of the building to ensure that motor vehicle exhaust is not pulled into and recirculated throughout the building;
- (b) better monitoring of air conditioning is required, especially for the offices located on the right side of the building where solar irradiation promotes thermal discomfort;
- (c) replacement of cleaning materials containing hazardous products in favor of cleaning supplies that contain less volatile chemicals.

Acknowledgments

The authors thank the efforts of the numerous colleagues who contributed to this work, especially Dr. M. S. Marques who contributed to GC/MS analyses and Mr. C. J. de Oliveira for help during sampling. This work was financially supported by FINEP and FUJB. Dr. L. S. R. Brickus thanks CNPq for a scholarship.

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Received for review April 2, 1998. Revised manuscript received July 26, 1998. Accepted August 4, 1998.

ES980336X